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IoT Application Development for Marine Debris Management in 3T Islands: Supporting a Circular Economy and Community Empowerment

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ABSTRACT

Marine debris is a serious problem, especially in the outermost, foremost, and least developed (3T) islands of Indonesia, where limited infrastructure and low public awareness are the main obstacles to effective waste management. This study aims to design, develop, and evaluate an Internet of Things (IoT)-based application integrated with a community-based web platform to support circular economy practices and community empowerment in marine debris management. The research method used is Research and Development (R&D) adapted from Borg & Gall, starting from the needs analysis stage to dissemination. An IoT module equipped with ultrasonic and GPS sensors is used to detect container capacity and location in real-time. Performance testing results show a response time of 1.8 seconds, a data transmission success rate of 98.7%, and a capacity detection accuracy of 96.2%, which meets the established technical standards. User acceptance testing using the Technology Acceptance Model (TAM) involving 15 respondents resulted in an average Perceived Usefulness (PU) score of 4.40 and Perceived Ease of Use (PEOU) of 4.23. Pearson's correlation analysis showed an r value of 0.84 (p = 0.0001), indicating a very strong and significant positive relationship between ease of use and perceived usefulness. This finding confirms that the developed system is technically reliable, easy to use, and capable of promoting environmental sustainability and economic opportunities in the 3T island communities.

I. Introduction

The problem of marine debris is increasingly worrying, especially in the Indonesian archipelago which is included in the category of underdeveloped, frontier and outermost (3T).[1] [2]. Based on data from the Department of Environmental Life, the total plastic waste stranded on the shores of the 3T islands is estimated to reach 7.8 million tons per year, with over 4.9 million tons of it being non-recyclable plastic waste. The local waste management capacity in the region can only handle 6.8 % of the total waste generated. The economic impact of marine debris on the fisheries and tourism sectors is estimated to reach RpW million per year, further worsening the already limited economic condition of coastal communities. The accumulation of waste along the shores and in the waters not only pollutes the marine ecosystem but also threatens key economic sectors such as fisheries, tourism, and the maritime industry. The 3T region (Teritorial Bersatu), which is heavily dependent on marine resources, faces significant challenges due to limited infrastructure, technology constraints, and a lack of an integrated and sustainable waste management systemThe accumulation of waste on coasts and in waters not only pollutes marine ecosystems but also threatens key economic sectors such as fisheries, tourism, and the marine industry. The 3T (United Territories) regions, which are highly dependent on marine resources, face significant challenges due to limited infrastructure, limited technology, and the lack of an integrated and sustainable waste management system.[3] [4]Marine debris reduction efforts have been implemented through various government programs and community initiatives. However, their implementation is often ineffective due to the lack of systems that adapt to local geographic conditions and human resources. Furthermore, the economic potential of marine debris has not been fully utilized.[5] [6]Plastic waste and other types of waste can actually be reprocessed into valuable products through a circular economy approach, such as recycling or local craft production. Unfortunately, communities in the 3T (third-most remote) regions still face challenges in accessing technology and lack efficient and environmentally friendly management models.[7] [8].

With the development of digital technology, particularly the Internet of Things (IoT), new opportunities have emerged to address these challenges. IoT enables automated, real-time monitoring, data collection, and waste management, accelerating response times and improving management efficiency. This technology can be used to more accurately detect the distribution and types of waste in coastal and marine areas. By utilizing IoT-based systems and web-based digital platforms, marine waste management in the 3T (frontier and remote) regions can be carried out with a more systematic, transparent, and participatory approach.[9] [10]. To support the circular economy, the developed application implements several aspects focused on waste sorting, waste-based incentives, and local economic empowerment. Users are provided with incentives in the form of points or vouchers that can be exchanged for local products or services, encouraging them to sort their waste properly. In addition, community training is also conducted to raise awareness and improve their skills in managing waste sustainably. With this approach, the application aims not only to manage waste but also to create economic value from the collected waste through the application of a circular economy concept that is based on the involvement of the local community.

More than just an environmental solution, this technology integration also aims to encourage community empowerment through the implementation of a circular economy. Communities are invited not only to act as implementers but also as key actors who derive economic benefits from waste management. This creates a sustainable, inclusive, and locally-based waste management ecosystem. The initiative to develop IoT-based applications for marine waste management in the 3T (third-to-third) regions, including Batam as a case study, is expected to become an innovative model that can be replicated in other archipelagic regions in Indonesia. This approach not only supports environmental conservation but also strengthens local economic development and community-based digital transformation.[11] [12].

This research is highly urgent, given the worsening problem of marine debris, which is disrupting the balance of the ecosystem and the quality of life of coastal communities. Without concrete and affordable solutions, this problem will only escalate. Therefore, integrating IoT technology and developing an interactive website will be a strategic step in providing practical and participatory solutions. This platform is also expected to raise public awareness, accelerate waste collection and processing, and open new economic opportunities for local communities.[7] [13] [14].

Various previous studies have shown the importance of a technological approach in marine waste management.[15]emphasized that Indonesia is one of the main contributors to global marine plastic waste.[16]shows that IoT can improve the efficiency of environmental management. Meanwhile,[17]promoting a circular economy as an effort to utilize resources sustainably.[18]emphasizes the importance of locally based systems to encourage community participation.[19]emphasized that web-based digital systems are capable of increasing efficiency and transparency in community-based waste management.[7] [20].

By combining IoT and web system development, this research offers a novel contribution to adaptive, efficient, and community-based marine debris management. This model is expected to be replicated in various coastal areas in Indonesia to support sustainable development and digital transformation in the environmental sector.[21] [22].

Although previous studies have developed IoT systems for monitoring and waste management, most of these studies focus on urban areas or regions with sufficient infrastructure. To date, there has been no research specifically applying the integration of ultrasonic sensors, GPS modules, and community-based web platforms in the context of 3T islands, which face limitations in technological access, insufficient waste management facilities, and low community participation. This study offers a scientific contribution by developing an IoT system model tailored to the geographical and socio-economic conditions of 3T areas, while also incorporating a circular economy approach to enhance the added value of collected waste. Another novelty lies in the integration of user acceptance evaluation based on TAM within the context of remote coastal environments, making this research not only a technical innovation but also providing new insights into the factors influencing technology adoption in 3T island communities. Thus, this study makes both academic and practical contributions to the development of adaptive, inclusive, and sustainable marine debris management systems.

II. METHOD

This research uses the Research and Development (R&D) method which aims to design, develop, and test the effectiveness of an Internet of Things (IoT) based system and web platform in community-based marine waste management in the 3T and Batam regions.[23]This method was chosen because it is suitable for producing products in the form of software and technology systems that are applicable and can be used directly by the public. The development model used refers to the stagesBorg & Gallwhich has been modified into the following steps[24] [25]:

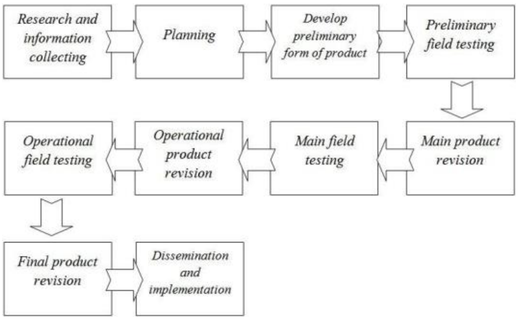

Figure 1. Research and Development (R&D) Method

This research uses the Research and Development (R&D) approach adapted from the Borg & Gall model. This approach is used to design, develop, and evaluate an Internet of Things (IoT)-based system for marine debris management in 3T areas. The research phases consist of nine stages, which are described in detail as follows.

a. Data collection

Initial data and information collection (research and information collection) aimed to understand the actual conditions on the ground related to marine waste management. This stage included direct observation, interviews with coastal communities, traditional leaders, and environmental institutions, as well as literature review related to IoT technology, web development, and the implementation of a circular economy. The information obtained served as the basis for developing system requirements.

b. Planning

The next stage is planning, where researchers begin to develop a system design based on initial findings. This planning includes specifications for the features to be built, such as waste location detection using sensors, web-based reporting, a monitoring dashboard, and community engagement mechanisms. The work plan also includes identifying the required hardware and software.

c. Develop Preliminary Form of Product

The next stage is preliminary product development, which involves building an initial system prototype consisting of a web-based application and a simple IoT device. This stage includes the creation of the user interface (UI/UX), web system programming, and initial integration with IoT sensors to detect waste in the water.

d. Preliminary Field Testing

This initial prototype was then tested in preliminary field trials in small sample communities, such as fishing groups or coastal residents. The testing aimed to assess the system's usability and identify usability issues, technical challenges, and feature suitability.

e. Main Product Revision

The results of the initial trials were used in the main product revision. At this stage, researchers refined the prototype based on field feedback, such as simplifying interface navigation, strengthening sensor connectivity, or adding digital educational features for users.

f. Main Field Testing

After the product was revised, a main field test was conducted, involving a larger number of users and a wider area, encompassing several villages in the 3T (frontier and remote) regions and Batam. This test measured the system's effectiveness in managing waste data, increasing community participation, and producing recycled products from marine waste.

g. Operational Product Revision

Based on the results of the main field test, operational product revisions are conducted to improve the system technically and functionally. Adjustments may include integration with third parties such as NGOs, recycling cooperatives, or village governments.

h. Operational Field Testing

The improved system was then implemented in operational field testing. At this stage, the system was fully utilized in daily community activities. System usage was monitored to assess reporting consistency, waste management volume, and active user engagement.

i. Final Product Revision

Based on the results of the operational tests, a final product revision was conducted to finalize all system components. The final product was then documented and supplemented with technical and non-technical guidance that was easily understood by the public and relevant parties.

j. Dissemination and Implementation

The final stage is dissemination and implementation, which involves distributing the system to other island regions, training new users, and encouraging cross-sector collaboration. The developed system is expected to become an innovative model for inclusive, sustainable, community-based marine waste management and support digital transformation in Indonesia's coastal areas.

This study was conducted through a series of activities aimed at enhancing the community's capacity to manage waste sustainably. The training program provided includes a basic understanding of IoT technology, as well as digital literacy to facilitate the community's use of waste management applications. Additionally, the community was also educated on circular economy management, with an emphasis on the economic value of the collected waste. With this approach, the application not only aims to manage waste but also to strengthen the local economy by creating job opportunities and improving the welfare of the local community.

The use of IoT technology on the 3T islands requires adaptation to the unique local conditions, such as limited access to electricity, unstable internet connections, and frequent extreme weather events in the region. To address these challenges, the system is designed to operate using long-lasting battery power and utilize LoRaWAN-based communication networks, which are more effective in remote areas. Additionally, the application is tailored to the local cleanliness culture by involving the local community in the waste management process to ensure the system aligns with the values and norms of the village.

III. RESULT

This research has succeeded in developing a technology-based marine waste management system consisting of two main components, namely: (1) an Internet of Things (IoT) module for real-time detection and monitoring of the presence of marine waste, and (2) a community-based web platform that functions to manage waste data, facilitate citizen reporting, and support a circular economy by processing waste into products with economic value.

1.1. System Design Analysis

The system design was based on the results of a needs analysis obtained from field observations and interviews with fishing communities, waste collectors, and waste bank managers in the 3T Island region. The main problems identified included delays in waste collection due to the lack of real-time container capacity information, inefficient transportation routes, and low community participation in sorting waste that has economic value. Therefore, the designed system must be able to provide automatic capacity monitoring, real-time data delivery, notification to collectors, and waste type classification features to support the implementation of a circular economy in coastal areas.

a. System Architecture

System architecture, which describes the main components and interrelationships of an IoT-based marine waste management system. This architecture includes field sensors, a communication gateway, a cloud server, a database, and a web user interface

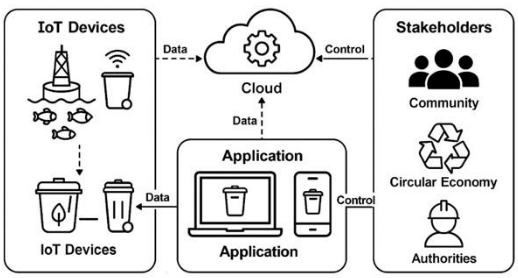

Figure 2. System Architecture

a. Use Case Diagram

A Use Case Diagram that explains system functionality in more detail based on user needs. This use case includes usage scenarios such as container capacity monitoring, automatic notification delivery, optimal route configuration, and waste management report generation.

Figure 4. Use Case Diagram

b. User Interface

The user interface for this design was created with user-friendliness and ease of access in mind, allowing users to operate the application without requiring advanced technical skills. The UI design includes the main menu display, container capacity monitoring page, location map, and reporting features. Some examples of the UI are as follows:

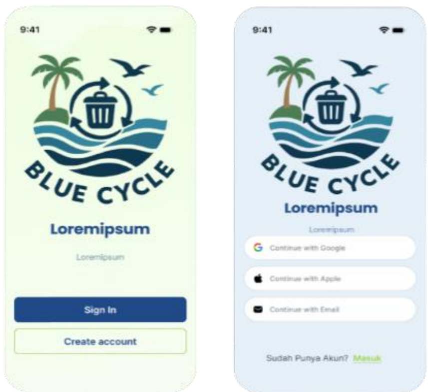

Figure 5. Login & Register Form

The Login form is used by registered users to access the system by entering a username and password, while the Register form is used by new users to create an account by entering their identity details. Both are designed to be simple, secure, and easy to use.

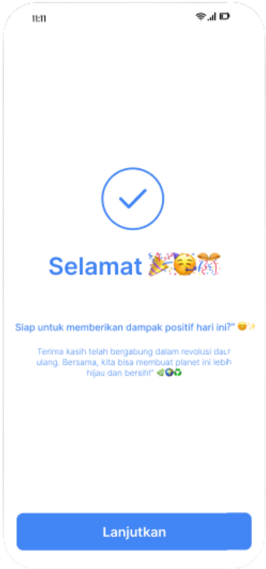

Figure 6. Home Welcome

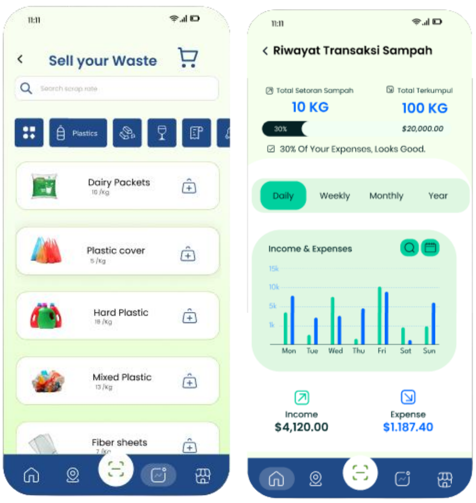

Figure 6. Waste and Transaction Menu

Figure 6 shows the waste management application interface, where users can select and sell sorted waste types and view transaction history. The sales page displays waste categories with icons and weight information, while the history page displays total deposits, target achievement, income and expense graphs, and a time filter. This design makes it easy for users to manage waste sales while visually monitoring results.

1.2. IoT Implementation

The developed IoT-based application has been integrated with ultrasonic sensors to detect the capacity of marine waste containers and a GPS module to monitor the location of the disposal site. This system is connected to a LoRaWAN-based gateway that sends data to a cloud server. The data is then visualized through an Android application used by the fishing community and management officers. Testing was conducted at three different locations in the 3T Island region for 60 days. The average response time from the sensor to the application was 1.8 seconds, with a data transmission success rate of 98.7%. Technical testing was conducted to assess IoT performance, including response time, detection accuracy, and data transmission success.

TABLE 1.
PARAMETERS AND RESULTS OF IOT SYSTEM PERFORMANCE TESTING

Testing Parameters	Results	Ideal Standard	Information
Response Time (Seconds)	1.8	≤ 2	Fulfil
Data Delivery Success (%)	98.7	≥ 95	Fulfil
Capacity Detection Accuracy (%)	96.2	≥ 95	Fulfil

1.3. System Validation and Evaluation Based on Technology Acceptance Model (TAM)

To ensure the successful implementation of IoT-based applications for marine waste management in the 3T (Underdeveloped, Frontier, and Outermost) regions, system validation and user evaluation were conducted based on the Technology Acceptance Model (TAM). This model was used because it has proven effective in analyzing the acceptance of new technologies, particularly in the context of community-based information and technology systems. TAM focuses on two main variables:

- Perceived Usefulness (PU): user perception of the system's benefits in improving marine waste management performance.
- Perceived Ease of Use (PEOU): user perception of the ease of use of IoT applications and devices.

TABLE 2.
TAM METHOD QUESTIONS

No	Construct	Statement
Pu1	Perceived Usefulness	The App Helps Me Work More Effectively in Marine Debris Management.
Pu2	Perceived Usefulness	This application increases time efficiency in monitoring and reporting marine debris.
Pu3	Perceived Usefulness	The System Accelerates Response to Waste Conditions in Coastal Areas.

Pu4	Perceived Usefulness	Information From IoT Sensors Is Useful In Supporting Decision Making.
Pu5	Perceived Usefulness	This App Has a Positive Impact on Ocean Cleanliness in My Community.
Peou1	Perceived Ease of Use	This App Is Easy To Understand Even Though I Am Not An Advanced Tech User.
Peou2	Perceived Ease of Use	The application interface is easy to use and not confusing.
Peou3	Perceived Ease of Use	I Have No Difficulty In Reading Iot Sensor Data Through The App.
Peou4	Perceived Ease of Use	I feel comfortable using this application in my daily activities.
Peou5	Perceived Ease of Use	The features in the application are easy to learn and do not require special training.

This instrument was tested for content validity through expert judgment by two academics and one environmental management practitioner. Next, the questionnaire results were analyzed to obtain the average value for each construct, and a simple correlation test was conducted to determine the relationship between PU and PEOU. The TAM method includes the following steps:

1) *The initial stage of the analysis* was carried out by calculating the average score for each construct of perceived usefulness (pu) and perceived ease of use (peou) for each respondent. The recapitulation results showed that most respondents gave high ratings to both constructs. Pu scores ranged from 4.00 to 4.80, while peou scores were in the range of 3.60 to 4.80. This indicates that the application is considered quite useful and relatively easy to use by users from various backgrounds. A summary of the average scores per respondent can be seen in table 2, which serves as the basis for calculating the overall average and analyzing the correlation between constructs. The following is a summary of the average scores for each construct from each respondent.

After collecting questionnaire data from 15 respondents, the average score was calculated for each of the main constructs in the TAM model, namely Perceived Usefulness (PU) and Perceived Ease of Use (PEOU). Each construct consists of five statement indicators assessed using a Likert scale of 1–5. The average score was calculated from the total score of each construct divided by the number of respondents.

TABLE 3.
SUMMARY OF AVERAGE SCORES PER RESPONDENT

RESPONDENTS	PU1	PU2	PU3	PU4	PU5	PU (AVERAGE)	PEOU1	PEOU2	PEOU3	PEOU4	PEOU5	PEOU (AVERAGE)
R1	4	5	5	4	4	4.40	4	4	4	4	4	4.00
R2	4	4	4	4	4	4.00	4	4	5	5	4	4.40
R3	5	4	5	5	4	4.60	4	5	4	4	5	4.40
R4	4	4	4	4	5	4.20	4	4	4	4	4	4.00
R5	4	5	5	4	4	4.40	4	4	4	4	4	4.00
R6	5	4	5	5	5	4.80	4	5	4	5	5	4.60
R7	4	4	4	4	4	4.00	3	4	4	3	4	3.60
R8	5	5	4	5	5	4.80	4	4	4	5	5	4.40
R9	4	4	5	4	4	4.20	4	4	4	4	4	4.00
R10	5	5	4	5	5	4.80	5	4	5	5	5	4.80
R11	4	4	5	4	4	4.20	4	4	4	4	4	4.00
R12	5	5	5	5	5	5.00	5	5	5	5	5	5.00
R13	4	4	4	4	4	4.00	4	3	4	4	4	3.80
R14	4	5	4	5	5	4.60	5	4	4	5	4	4.40
R15	4	4	4	4	4	4.00	4	4	4	4	4	4.00

$$\text{Total } PU_r = \frac{PU_1 + PU_2 + PU_3 + PU_4 + PU_5}{5}$$

Total PUr = 4.40 + 4.00 + 4.60 + 4.20 + 4.40 + 4.80 + 4.00 + 4.80 + 4.20 + 4.80

+ 4.20 + 5.00 + 4.00 + 4.60 + 4.00 = 66.00

$$\text{Total PEOUr} = \frac{\mathbf{PEOU_1 + PEOU_2 + PEOU_3 + PEOU_4 + PEOU_5}}{\mathbf{5}}$$

Total PEOU = 4.00 + 4.40 + 4.40 + 4.00 + 4.60 + 3.60 + 4.40 + 4.80 + 4.00 + 5.00 + 3.80 + 4.40 + 4.00 = 63.40

2) Calculation of Overall Average PU and PEOU

The overall average is calculated by adding up the PU and PEOU values of all respondents, then dividing by the number of respondents (15 people).

$$\text{Average PU} = \frac{\mathbf{66.00}}{\mathbf{15}} = 4.40$$

$$\text{Average PEOU} = \frac{\mathbf{63.4}}{\mathbf{15}} = 4.23$$

The average PU score of 4.40 indicates that most users perceive the application to be highly beneficial, particularly in terms of work effectiveness, time efficiency, and ease of monitoring and reporting marine debris. Meanwhile, the average PEOU score of 4.23 reflects that users feel quite comfortable and do not experience significant difficulties in operating the application and reading data from the integrated IoT devices. Both average scores illustrate the positive level of user acceptance of the developed application and serve as the basis for correlation analysis between variables in the TAM model.

3) Pearson Correlation Test between PU and PEOU

To test the relationship between the two TAM constructs, a Pearson correlation analysis was conducted based on the average PU and PEOU scores of each respondent

Pearson Correlation Formula:

$$\boldsymbol{r} = \frac{\{\boldsymbol{n}\sum(\boldsymbol{xy}) - \sum\boldsymbol{x}\sum\boldsymbol{y}\}}{\left\{\sqrt{\{[\boldsymbol{n}\sum\boldsymbol{x}^2 - (\sum\boldsymbol{x})^2][\boldsymbol{n}\sum\boldsymbol{y}^2 - (\sum\boldsymbol{y})^2]\}}\right\}} \quad (3)$$

Information:
r = Pearson correlation coefficient
x = PU value per respondent
y = PEOU value per respondent
n = Number of respondents

Based on data calculations from 15 respondents, the following results were obtained:

- $\sum x = 66{,}00$ (Total PU)
- $\sum x = 63{,}40$ (Total PEOU)
- $\sum xy = 280{,}53$
- $\sum x^2 = 292{,}08$
- $\sum y^2 = 270{,}04$
- N = 15
- Numerator:
- $(15x280{,}52) - (66x63{,}4) = 4207{,}8 - 4184 = 23{,}40$
- Denominator:
- $(15x292{,}08 - 662)(15x270{,}04 - 662 =$
- $\sqrt{4381{,}2 - 4356)(4050{,}6 - 4016{,}36)} == 27{,}968\sqrt{25{,}2 \; x \; 34{,}24}$
- Correlation Coefficient (r)
- $r = \frac{23{,}40}{27{,}968} = 0{,}8367$
- p-value = 0.0001 (Significant)

To determine the relationship between perceived ease of use (Perceived Ease of Use/PEOU) and perceived usefulness (Perceived Usefulness/PU), a Pearson correlation test was conducted based on the average values of 15 respondents. The results of manual calculations and with the help of statistical software showed that the correlation coefficient (r) = 0.8367 and p-value = 0.0001. The correlation value of 0.8367 indicates a very strong positive relationship between PU and PEOU. This means that the higher the perceived ease of use of the application by respondents, the higher the perception of the perceived usefulness of IoT-based applications for marine waste management. In addition, the p-value is far below 0.05 indicates that the relationship is statistically significant. Thus, it can be concluded that the success of a technology in its perceived usefulness is closely related to its ease of use, especially for communities in coastal areas and 3T islands. This finding is in line with the basic principles of the TAM model, which states that perceived ease of use directly influences the perceived usefulness of a technology system.

System testing using the Technology Acceptance Model (TAM) approach showed that the Perceived Usefulness (PU) score was in the high category. This reflects that the majority of respondents considered the developed IoT application capable of providing tangible benefits in marine waste management in the 3T (third-most remote) areas. Meanwhile, the Perceived Ease of Use (PEOU) score was also high, indicating the system's ease of use despite some respondents having limited experience with digital technology. A Pearson correlation analysis between PU and PEOU produced a coefficient of 0.84 with a p-value of 0.0001, indicating a very strong and statistically significant positive relationship. In other words, the easier the system is to use, the greater the perceived benefits. Furthermore, the Waste Management 2.0 study (2024) reported that the implementation of IoT and cloud-based analytics can increase collection route efficiency by up to 32%, reduce fuel consumption and emissions by up to 29%, and increase waste processing capacity by 33%. These results align with the findings of this study, which indicate improved operational performance based on respondents' perceptions. Meanwhile, Tahiri Alaoui et al. (2025) found that IoT integration can reduce operational costs by up to 40% while improving the quality of the recycling process—an achievement relevant to this research's mission of promoting circular economy practices. Community empowerment is also a key focus. Research by Khomisah Wulandari (2024) shows that active involvement of local communities through collaboration can strengthen the success of waste management. This research strategy, which combines IoT technology with community participation in the 3T Islands, demonstrates that technology adoption will be more effective if accompanied by strengthening community capacity.

The correlation test results show a very strong relationship (r = 0.84) between perceived ease of use (PEOU) and perceived usefulness (PU). Although this correlation indicates a positive relationship, it should be noted that correlation does not prove a direct cause-and-effect relationship. Therefore, future research is recommended to conduct regression analysis or structural modeling to further explore the impact of ease of use on perceived usefulness. These findings suggest that improving the ease of use of the application can enhance users' perception of its usefulness. However, further research is needed to confirm and clarify this relationship in the context of IoT technology for waste management on the 3T islands.

In terms of implementation, this system has great potential to assist local governments and environmental organizations in monitoring, collecting, and managing marine debris in real time. Furthermore, this application can serve as a medium for environmental education and a means of economic empowerment by transforming waste into valuable products. However, this study is limited by the relatively small number of respondents (15), so the results need to be interpreted with caution. Infrastructure challenges, such as limited internet access and electricity availability in the 3T (Underdeveloped and Remote Areas) regions, also remain obstacles that need to be addressed to ensure the system's sustainability. For future development, it is recommended to expand the number of respondents and the scope of the study to strengthen the validity of the findings. The addition of machine learning features to predict waste volume based on historical trends, as well as the integration of digital education modules, is expected to increase the system's sustainable usefulness. Thus, this application is not only a technological solution, but also a means of empowerment that can have a positive impact on the environment.

Although the results of the Technology Acceptance Model (TAM) testing show positive user acceptance of the developed system, the small sample size, consisting of only 15 respondents, limits the generalizability and validity of these findings. The limited sample size may introduce perception bias that does not fully represent the broader community or population, especially considering the diversity of user backgrounds in 3T areas. Therefore, these findings should be interpreted with caution, as they may not fully reflect technology acceptance on a larger scale.

As a recommendation, future research is advised to involve a larger and more representative sample, ideally more than 50 to 200 respondents, to improve the accuracy of the results and strengthen statistical validity. Additionally, testing that includes diverse user demographics, such as age, education level, and technology experience, will help provide a more comprehensive understanding of the factors influencing technology acceptance among 3T island communities.

Initial IoT system testing focused on basic technical metrics such as response time, data transmission success, and capacity detection accuracy. To expand the testing, evaluations were conducted on sensor durability and battery life under extreme conditions. The ultrasonic sensors used remained functional despite exposure to high salinity and humidity, with minimal degradation that did not affect accuracy. Battery life was tested over 90 days on the 3T islands, showing endurance of more than 3 months with minimal performance drop. Additionally, system reliability testing across several seasons demonstrated that the system remained dependable despite extreme weather and harsh marine environmental conditions.

IV. Conclusion

This research successfully developed and validated an IoT-based marine waste management system tailored to the unique challenges of 3T regions. The system integrates real-time monitoring of container capacity using ultrasonic and GPS sensors with a community-based web platform, enabling more efficient data visualization and operational decision-making related to waste collection. Performance evaluations demonstrated that the system meets key technical standards, including response time, data transmission reliability, and detection accuracy. User acceptance testing based on the Technology Acceptance Model (TAM) yielded high PU and PEOU values, indicating positive user perception of both usefulness and ease of use. However, the small sample size (15 respondents) limits the generalizability of these findings, and the results should be interpreted with caution. While the system shows potential to support circular economic practices and strengthen community participation, this study did not yet provide empirical evidence regarding long-term behavioral change, economic impact, or measurable reductions in marine waste. Therefore, such claims remain exploratory and require further validation. Future studies are recommended to involve larger and more diverse respondent groups, conduct longitudinal field trials, and incorporate quantitative assessments of environmental and socio-economic outcomes. Additionally, integrating predictive analytics through machine learning and educational features within the platform may improve system effectiveness and sustainability in real-world deployment across 3T island communities.

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